How do airplanes fly?
Aeronautic Education Made Easy

Engineering appeals to students because of its concrete nature. Aeronautics is particularly exciting to students because it is a very high profile form of engineering and because flight is something which all students have wondered about at some time in their lives. It is important to try to reach the students who are not currently pursuing science because they find it uninteresting or unattainable and help them to see its practical applications. By introducing students to engineering at a younger age and getting them excited about what they are learning, perhaps more of them will maintain this interest throughout their lives.

Included here is information which we hope will encourage more teachers to introduce aeronautics into the classroom. We include a hands-on curriculum outline with suggested lessons and experiments, instructions on how to make a wind tunnel to aid in teaching aeronautics, software which may be used in conjunctions with a ULI board and force probes to measure lift and drag forces in a wind tunnel, and instructions on how to use this software. By clicking on the small arrows in the lower right hand corner of the card, you can go forward or backward through the entire curriculum one card at a time. Most sections are made up of more than one card. The curved arrow in the upper right hand corner will return you to this card at any time. To print out a card, you can select "Print Card" under the File menu. To print out the entire text section of a card when the text is scrolled, select "Print Field" under the File menu. If you have any questions or comments, please call the AIAA help line at (617) 627-3013.

This curriculum has been designed to help teachers bring aeronautic education into the classroom. The explanations and descriptions do not assume any knowledge of aeronautics, and were designed to be unintimidating and easy to understand. Depending on the age and skill level of the students, you may want to skip some sections of the curriculum. Older students, for example, probably have some intuitive sense of the properties of air, so you may want to shorten or omit this section. Many of the sections, especially the wind tunnel section, can be expanded. In our experience, we have found the wind tunnel to be something that helped and interested students immensely when they were given a chance to experiment with it themselves. For this reason, you may want to allow enough time for each student to get first-hand experience with the tunnel. A wind tunnel is an investment which we feel is well worth while and can be used at many different grade levels and for years to come.

The objective of this curriculum is for students to come away with a basic understanding of how planes fly and with an interest in aeronautical engineering. We have tested this curriculum with many different age groups, some as young as first grade. With first graders, we chose to concentrate on drag forces, which are more intuitive than lift forces. Even at this level, students were able to gain a solid understanding of drag.

Curriculum Outline

- Properties of Air
  - air has weight and takes up space
  - air moves
  - air exerts pressure, a measure of the amount of "push" something has
- Basic relationships
  - pressure vs area : Pressure = Force/Area
  - pressure vs velocity : increase in velocity leads to decrease in pressure
  - lift vs velocity : lift force is created when there is a pressure difference
- Using a wind tunnel to :
  - explore lift
  - explore drag
  - explore stall
  - take computer measurements of lift and drag forces
- How are planes controlled? An experimental unit to discover how the pilot controls the plane using ailerons, elevators, and the rudder.
- How are planes powered? Simple experiments to explore:
  - propeller planes
  - jet planes
- How are airplanes like birds? A biological comparison for students who may find physical science uninteresting or intimidating.
- Wing design and aspect ratio - an introduction to taking data, making measurements, applied math, and making comparisons in determining how wing size and shape affect flight.
- Final design competition to reinforce all of the concepts.

Balloon Scale : Air has weight

Objective: This demonstration shows that air has weight even though it is invisible.
Materials: Two balloons of the same shape, a wooden rod, string.
Procedure: Blow up both of the balloons so that they are the same size and tie them with string. Tie the strings to either end of the rod. Tie another piece of string to the center of the rod, so that the balloons balance as shown. Let the air out of one of the balloons. The balloon scale will now be tilted.
Explanation: When the balloons are both filled with air, they weigh the same, and therefore balance. When the air is let out of one of the balloons, they no longer have the same weight. The balloon filled with air is heavier than the balloon with no air inside it, and therefore drops. .

Air Velocity

Objective: Depending on the age of your students, you may want to introduce the concept that air moves, and in fact can have speed.
Procedure: Have the students observe trees moving on a windy day. Make paper fans and have the students create their own wind. Talk about the airflow students feel when the car window is open.
Explanation: Although you can't see air moving, it is moving all the time. Air can travel with a velocity, just like a car can. It constantly moves around and over surfaces.

What is Pressure?

Objective: To illustrate the concept of pressure to students using water pressure which they may be able to visualize more easily than air.
Materials: A plastic one-liter soda bottle with three small holes, three push pins to plug up the holes, a bottle cap, and a shallow water container.
Procedure: Fill the bottle with water. Observe what happens when you do each of the following.
• Uncap the bottle and remove one of the pins.
• Cap the bottle.
• Squeeze the capped bottle, first lightly, then hard.
• Remove all three pins and the cap.
• Try removing all combinations of pins with the cap off.
Explanation: With the cap on, no air can get into the bottle and push the water out of the holes. When the cap and pins are removed, the pressure forces water out of the holes. Because there is more water pushing down on the bottom hole than the top hole, the bottom stream is pushed farther than the top stream.

Pressure II: Air Pressure

Objective: To demonstrate that air exerts pressure.
Materials: A large piece of paper and a ruler.
Procedure: Put the paper down on a table with the ruler underneath it so that about one third of the ruler is hanging off the edge of the table. The student should try to push the ruler (not too hard or the ruler may break) and launch the paper into the air.
Explanation: The student will not be able to lift the paper because there is air pressing down on it. The surface of the paper is large, and therefore there is enough air pressure on it to prevent it from being moved by the force applied to the ruler.

More Air Pressure

Objective: To further illustrate the concept of air pressure.

Materials: A coffee can or wide mouthed jar, a large plastic bag with no holes, and string or tape.
Procedure: First, put the plastic bag inside the jar so that the mouth of the bag hangs outside of the jar. Tie or tape the bag around the mouth of the jar so that the seal is airtight. Have the students reach into the jar and try to pull the bag out. Next, untie the bag and fill it with air. Attach the bag upside down to the jar as before.   Ask the students to try to push down on the bag.
Explanation: When the bag is inside the jar, it is being pushed on by the air outside the jar. To lift it out, the student has to lift not only the bag, but the air as well. When the bag is full of air, however, it acts like a balloon. The pressure on the inside of the bag is greater than the pressure on the outside, and this makes it difficult to push down on the bag.

Still More Air Pressure

Objective: To illustrate the concept of air pressure using a phenomenon which students are probably familiar with.
Materials: A drinking straw.
Procedure: Have students suck water into the straw and put their finger over the top of the straw. They can now lift and tilt the straw and no water will escape. When they remove their finger, the water will come out.
Explanation: By holding their finger over the top of the straw, the student is preventing air from coming in, so there is no air pushing down on the water. Air is still pushing on the uncovered bottom, though. When they remove their finger the air comes in through the top of the straw and pushes the water out.

Force versus Pressure

Objective: This lesson is to help the students understand the concept that the same force can result in different pressures depending on the surface area.
Materials: Each student should be given a flathead nail.
Procedure: First, the students gently press the flat end of the nail against their finger and notice how much pressure they feel. Next they turn the nail around and press the pointed end against their finger with the same force. They should, hopefully, feel a greater pressure.
Explanation: Even though they are exerting the same force on their finger, they will feel greater pressure when they press with the pointed end of the nail. This is because the force is concentrated in a smaller area. This concept can also explain why sharp knives cut better than dull knives. The sharper the knife is, the more concentrated the force and the greater the pressure.

Pressure versus Velocity

Objective: This demonstration should show that when air flows faster, lower pressure results.
Materials: Each student should be given two straws and a cup half filled with water.
Procedure: The students hold one straw vertically in the water and the other horizontally so that the ends are close together. By blowing air into the horizontal straw, the student causes water to spray out of the vertical straw.
Explanation: By blowing into the straw, the student is increasing the velocity of the air. This increase in velocity causes a decrease in pressure above the vertical straw.   When there is a difference in pressures, a force is always created from high pressure to low pressure. This force is what causes the water to come up.

Pressure versus Velocity

Objective: This lesson is to help explain the concept that faster air flow results in less pressure.
Materials: A clear funnel and a ping pong ball.
Procedure: With the funnel upside down, hold the ping pong ball inside and blow into the small end as you let go of the ball. Students are usually surprised to see that the ball does not fall but stays lodged in the end of the funnel.
Explanation: By blowing into the funnel, the velocity of the air is greater above the ping pong ball than below. When the air reaches the larger cross section, it spreads out and thus slows down. The pressure is less where the air is going faster, above the ball, and greater where the air is going slower, below the ball. A force is created going from high to low pressure, and this keeps the ball up despite gravity.

Pressure versus Velocity

Objective: This demonstration shows that greater velocity causes lower pressure.
Materials: Two books, one sheet of paper, and a straw.
Procedure: The books are placed on a desk side by side with a space in between them. The paper is placed over both books so that it bridges them. The student uses the straw to blow air underneath the paper. This causes a downward force on the paper, and it moves down in the center.
Explanation: Once again, the increase in the velocity of the air underneath the paper causes a lower pressure underneath the paper than above the paper. A force is created from higher to lower pressure, and this force pushes the paper down.

Lift versus Velocity

Objective: This demonstration takes what the student has learned about velocity and pressure and introduces the concept of lift.
Materials: Each student should have a strip of paper 1-2 inches wide and 6-8 inches long.
Procedure: The student places the paper under their lower lip and holds it there with their index finger horizontal so that it falls over their finger. They then blow over the paper, and the paper rises. The student can put paper clips on the end of the strip and can be lifted in the same manner.
Explanation: By blowing over the paper, they are increasing the velocity of the air over the paper and thus decreasing the pressure over the paper. The pressure underneath the paper is therefore greater, and the paper rises. This is the basic concept of lift. It can be applied to a Frisbee as well. The Frisbee is shaped so that air travels faster over the top than under the bottom. When the Frisbee moves through the air, therefore, it rises.

Lift Vs Velocity II: the jumping token

Objective: This demonstration shows how increasing the velocity of the airflow over an object can cause it to lift.
Materials: A plastic or cardboard game token and a saucer.
Procedure: Place the token near the edge of the table with the saucer a little behind it. Blow across the top of the token and try to get it to land in the saucer.
Explanation: By increasing the speed of the air going over the token, you are decreasing the pressure on top of the token. Since there is now more pressure below the token than above it, the token rises and is lifted into the saucer.

Lift on an Airplane Wing

Objective: This exercise demonstrates how the shape of an airplane wing helps it to obtain lift.
Materials: A ruler, a strip of paper about 28 cm by 8 cm, and some tape.
Procedure: Fold the strip of paper in half and tape the top edge about 3 cm from the bottom edge. This will make the top surface curved and give the paper the shape of an airplane wing. Slide the ruler into the fold of the paper. Blow on the front of the wing.
Explanation: Because the top surface of the wing is curved, the air has to travel a greater distance over the top of the wing than over the bottom of the wing. This means that the air has to go faster over the top of the wing than over the bottom. This causes a pressure difference. There is more pressure on the bottom of the wing than on the top, and the wing is pushed upward.

Using the Wind Tunnel: A Demonstration of Lift

Objective: This is an example of the kind of experiments which can be done using the wind tunnel. This experiment demonstrates how varying the angle of a wing can increase or decrease the lift.
Materials: A rectangular piece of balsa wood with two holes so that it can slide up and down on a rectangular wire frame.
Procedure: Placing the wing inside the tunnel and varying the angle of the wing will cause the wing to rise and fall. When the wing is horizontal, it will not rise at all. A small angle will cause the wing to rise slowly, while a larger angle will cause the wing to rise more quickly.
Explanation: As the air approaches the wing, it takes two paths. Some of the air travels over the wing while some of it travels under the wing. When the wing is angled, the air going over it travels more quickly than the air going underneath, the pressure above is less, and the wing rises.

Using the Tunnel to Illustrate Drag

Objective: This experiment is designed to introduce the concept of drag using the wind tunnel.
Materials: Several different Styrofoam shapes.
Procedure: The shapes are attached to strings which allow them to slide up and down freely. The strings are then hung diagonally in the wind tunnel so that when the tunnel is turned on, they will slide up the strings at different speeds. The shapes that travel up the string most quickly are those with the most drag.
Explanation: The shapes with the least drag are the shapes which allow air to flow smoothly around them. Those with the most drag are the ones which interrupt the flow of air the most abruptly. Students have probably all experienced drag by putting their hands out of a car window when it was moving.

Using the Tunnel to Illustrate Drag II

Objective: This demonstration allows students to learn about drag through problem solving.
Materials: Two or more ping pong balls cut in half, a few tinker toys or wooden dowels, and a stand which allows a dowel to spin freely in it.
Procedure: Glue the half ping pong balls onto short dowels or tinker toys. Place them in the round tinker toy piece as shown. Ask students if they will turn when placed in the wind tunnel and why. Turn one of the cupped pieces around. Ask again if it will turn and why. Give the student more pieces and see if they can make a spinner using 3 or 4 cupped shapes.
Explanation: The spinner will only spin if one of the pieces has more drag than the other. In the configuration above, the top piece is cupped, and therefore has more drag than the bottom piece which

is smoothed. Thus it will spin. But if one of the pieces were turned around, top and bottom drag would be the same, and it would not.

Using the Wind Tunnel to Illustrate Stall

Objective: This experiment demonstrates the concept of stall as it affects flight.
Materials: A model plane can be used to demonstrate this concept. Attach a row of thin thread or string along the wings of the plane.
Procedure: Put the plane in the tunnel and vary its angle of attack. With a small angle of attack, the string should be straight pointed directly behind the plane. As the angle of attack gets bigger, the string will start to move around wildly.
Explanation: As the air hits the plane at a greater angle, it can no longer flow around the wings smoothly. Vortices, or swirls of air, occur behind the wings and the plane no longer lifts. This is called stall.

Taking Measurements With a Computer

These are just a few of many wind tunnel experiments to give you some ideas. Once the students have understood the basic concepts of lift and drag, it is helpful for them to be able to see these forces first hand. Investing in a Universal Lab Interface (or ULI) board, will permit you to measure lift and drag forces using a computer. By hooking up Hall effect force probes to an object in the wind tunnel, it is possible to take these measurements and graph them so that the students can compare different designs and are able to see how varying the angle of attack and wind speed can effect lift and drag forces. Software which interprets and graphs these readings is included on this disk. Many different objects can be tested in the wind tunnel; among these are geometric shapes, cars, planes, or even Superman.

Taking Measurements: Without a Computer

It is also possible to take measurements less expensively without the use of a computer. Attach the model or shape to a rod with a thinner pointer protruding at a 90 degree angle as shown. Fit the rod into a slotted tube as shown, so that the pointer fits through the slot. A rubber band or spring can be attached to the rod and base as resistance. As the model is placed in airflow, the lift force will cause it to rise. The pointer will serve as a measure of the lift force on the model.

How do Pilots Control Airplanes?

Objective: Now that the students have a basic understanding of how lift and drag forces affect the flight of an aircraft, they will probably be wondering how pilots are able to steer airplanes. Because the plane travels in air, the pilot must be able to move the plane up and down as well as left and right. A good way to help students understand how planes are controlled is to guide them through experimentation in which they will discover the relationships for themselves.

Materials: Each student should be given a small balsa glider. These planes are sold at toy stores and are inexpensive. The students should put the plane together as directed by the package. They should then cut five 3 x 5 cm squares from index cards or oak tag. These squares should be taped onto the wings and tail of the plane to represent the moving parts of real airplanes which pilots use to control the movement of the plane. The flaps on the wings are called ailerons; the flaps on the horizontal stabilizer are called elevators; and the flap on the vertical fin is called the rudder.

Procedure: Now the students are ready to experiment with the glider. Ask them questions like the following to guide them through their exploration.

- What happens when you fold the left aileron up? What happens when you fold down the left aileron? What happens when one aileron is up and the other is down?
- What happens when you move the rudder to the right? To the left?
- What happens when you move the elevators up? Down?
- What happens when you move the wings forward? Back?
- What happens when you move the wings to the left or right so that they are off center?
- What happens when you add paper clips to the plane at different locations?
- How can you make your plane fly straight for the longest distance?

Explanation:

There are several ways to make the plane turn left or right. To turn the plane right, the pilot could raise the right aileron, so that the right side of the plane is pushed down. Lowering the left aileron will cause the left side of the plane to be pushed up. This is called banking and will tilt the plane right. The pilot does this as the plane is turning, just like a bike rider will lean into a turn in the road. Turning the rudder to the right will cause the plane to veer right. Moving the wing to the left relative to the body will also cause the plane to turn right, because there will be more lift on the left wing than the right wing and this will tilt the plane. To turn the plane left, simply reverse all of these directions.

To make the plane go upward, the pilot raises the elevators on the tail. As the air flow hits the elevators, the tail of the plane is pushed down, and therefore, the nose of the plane is pushed up. This causes the plane to rise. To make the plane go downward, the pilot tilts the elevators down. This pushes the tail of the plane up and the nose down and causes the plane to go downward.

Adding paper clips to the plane and moving the wing forward and backward will allow the student to experiment with the center of gravity of the plane. If most of the weight of the plane is in the front, the plane will tend to nose downward. If the weight of the plane is balanced, the plane should be suited for long distances. If most of the weight is in the back, however, the nose of the plane should be up, and with experimentation, the student may be able to fly the plane in a loop-the-loop.

How are planes powered? Propeller planes

Objective: In order to achieve lift, a plane must have "thrust". In other words, the plane must be moving forward. Some planes use propeller engines to give them thrust. Here is a simple working propeller.
Materials: A piece of oak tag 10 x 10 cm, a spool, a small dowel, string, and tape.
Procedure: Cut and fold the oak tag as shown. Attach the dowel to the propeller with tape. Place the dowel in the hole in the spool. Wind the string around the dowel and pull the string quickly to start the propeller upward.
Explanation: The propeller works by compressing the air underneath it. By compressing this air, the pressure underneath is increased, and the propeller will rise. This is how a helicopter flies. In airplane engines, the propeller spins vertically and thus the air is compressed behind the propeller and this pressure moves the plane forward.

How are planes powered? Jet planes

Objective: Another way of creating thrust is using a jet engine. Students are often curious about jet engines, so this discussion will introduce them to the principles involved.
Procedure: Blow up a balloon and then let it go watching how it is propelled as the air escapes.
Explanation: The air inside a balloon is under pressure. When you let go of the balloon, the air rushes out through the opening and pushes the balloon forward. Jet engines work similarly, except they operate by burning fuel. Air is pulled into the front of the engine by a fan. As the fuel is burned, it releases very hot, compressed gases which are at great pressure. These expanded gases escape through the back of the engine and as they rush out, they move the plane forward.

How are planes like birds?

Some students may feel more comfortable talking about aerodynamics in terms of biological organisms. It may be helpful for you to talk about how birds fly. Birds are different from airplanes in that they are able to get both lift and thrust from their wings and thus do not require a propeller or engine. A detailed explanation of how they accomplish this is too complicated to go into in depth, but here is a very simplified explanation. As a bird flaps its wing, it is not just moving its wing up and down. The wing is actually moving down and forward during the down stroke and up and back during the upstroke, so the path of the wing looks like a figure eight. Because a bird's wing is jointed, it is able to get lift from the inside part of its wing and thrust from the outside part of its wing which acts much like a propeller as it travels up and down.

When birds glide or soar, however, they act much like gliding airplanes and the balsa gliders the students used earlier, and the same principles of flight apply. Birds have an advantage over airplanes, though, because of their feathers, which allow them to maintain the optimum combination of lift and drag forces at all times. The feathers on a bird's wing make its top curved, much like an airplane wing. This insures that the air will have to travel farther over the top of the wing than under the bottom, which leads to a velocity and pressure difference, and therefore a lift force (just as we saw in our exploration of lift). Birds are also able to control their movement using their feathers. By changing the shape of their wings and tail they can change the direction of their flight, just like a pilot is able to change direction by controlling the elevators and ailerons of an aircraft.

When a bird glides, it uses very little energy, because it only has use enough energy to keep its wings horizontal. Glider planes, in fact, are not powered, and work the same way. A gliding bird will angle itself just enough toward the earth so that the lift force on the wings balances the weight of the bird. Potential energy is lost only because the bird also has to overcome drag forces on its body. Birds are able to change their wingspan and drag by moving their body and feathers so that they can maximize their glide distance.

When a bird soars, it uses energy from winds in order to go higher or faster. There are several types of soaring. Slope soaring is when a bird flies in an airstream which is moving over a hill or ocean wave. The bird maintains the same distance from the ground as it flies, but since it is going along a hillside, it is gaining relative height or potential energy. Thermal soaring is when birds use rising warm air currents to lift them. Once they have gained height, they are able to glide until they come to another thermal air shift. Gust soaring is when birds use random gusts of wind to propel them. Different birds are suited for different types of soaring. Eagles and vultures have short, wide wings with slotted tips which are suited for thermal soaring, while gulls have long, narrow wings which are suited for slope soaring.

Watching a bird land, you can see how the bird uses aerodynamics to aid in a smooth landing. Most of the time, a bird has to be much more precise in landing than an airplane pilot; it must land on a branch as opposed to a runway. During landing, the bird will increase its angle of attack until it stalls. This decreases both its speed and its lift so that it can land safely. The bird also will spread its feathers apart and lower its legs so that they act much like wing flaps and slats which a pilot uses to increase drag when landing a plane.

Birds also have developed organs suited to navigation, just like an airplane pilot has instruments to help in navigating. Birds have well developed vision. They can see where the sun is even when it is overcast, and they use the sun to help them find their way. They are also able to use star patterns in the same way. A bird's hearing is developed so that they can hear sounds which humans cannot. This helps them to hear wind and waves from farther away. Birds can intuitively detect changes in air pressure, which helps them to fly at constant height. Birds also have special organs near their brain which enable them to locate the geomagnetic fields of the earth. This special sense is very useful in helping birds navigate.

Comparing planes to birds can be very interesting. When aircrafts were first being designed and tested, scientists looked to how birds are constructed for ideas and inspiration. In many ways, humans have tried to imitate the flight of birds. We use thin wings like a bird. A bird's body is designed to be very aerodynamic in order to reduce drag, and aircraft designers have mimicked this aerodynamic shape. Aircrafts also have tails which work like a bird's and use wheels in the same way that a bird uses its feet. Man has developed instrumentation to take the place of the navigational organs which birds possess. So although it is impossible to create an airplane which propels itself as efficiently and gracefully as a bird does, biological science has definitely had a great influence on aeronautical engineering.

Wing Design and Aspect Ratio

Objective: To experiment with different wing designs, to use applied math, and to give the student an opportunity to take data.
Materials: Paper and tape.
Procedure: Have students make paper airplanes with different sized wings and test the planes. An easy way to make paper planes is to fold a piece of paper in half lengthwise and then unfold (1). Fold one side in half (2). Fold the same side in half again (3). Fold this over the first crease you made and tape (4). Crease the plane at the center point and fold down the wings as shown (5). Have the students make several planes of different sizes and have them make a table recording the wing size (length and width), the wing area, the wing aspect ratio, and how far the plane flew on several different tests.
Explanation: The aspect ratio is a measure of how square the wing is. It is calculated by dividing the wing length from tip to tip by the wing width. Generally, higher aspect ratios are more efficient during low speed flying. Hopefully, students will see some correlation between wing shape and flying distance.

Final Design Competition

It is fun to finish the unit on aeronautics with a design competition. This allows students to build their own paper airplanes and compete in a variety of categories. A competition like this one makes students think about everything they have learned about how planes fly, and it also allows them to be creative and do some problem solving. You can have them compete alone or in teams to see whose plane can go the farthest distance, can come closest to a target to the right or left of the thrower, can do the best trick, or is simply the most innovative design. Students should be encouraged to decorate their planes and to be able to justify their design decisions with what they have learned about how planes fly.